

Using MBSE to Evaluate Fractionated Space Systems

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June 25, 2013

AGENDA

- Background
- Summary of ASDA work
- Overview of the user process for modeling
- Cost Modeling
- Discrete Event Modeling
- Some Results
- Wrap-up

JPL is part of NASA and Caltech

- Federally-Funded (NASA-owned) Research and Development Center (FFRDC)
- University Operated (Caltech)
- \$1.6B Business Base
 - NASA Science 72%
 - Non-NASA 12%
 - Mission Operations 12%
- 5,000 Employees
 - R&D Staff 59%
 - 32% PhD
 - 32% Masters
- Great place to work!
- www.jpl.nasa.gov

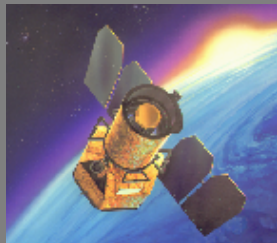




National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Twenty-three spacecraft, nine instruments across the solar system (and beyond)



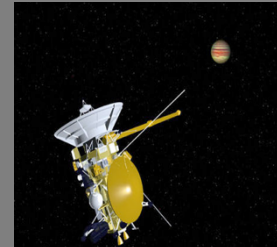
GALEX



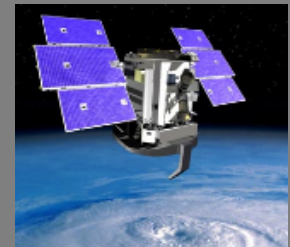
Kepler



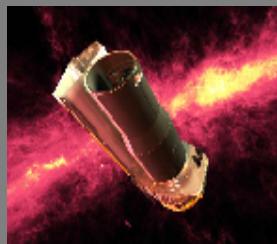
Mars Odyssey



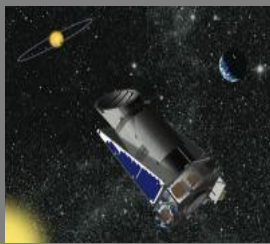
Cassini



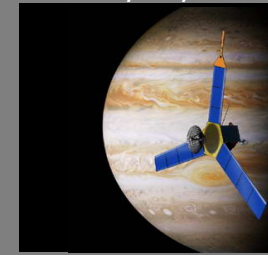
CloudSat



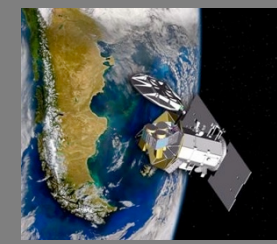
Spitzer



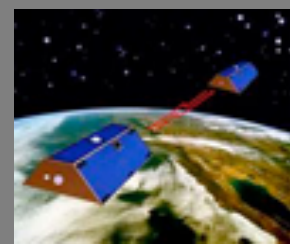
ACRIMSAT



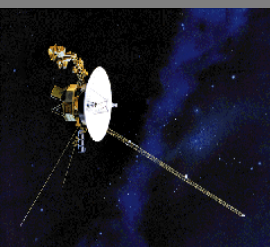
Juno



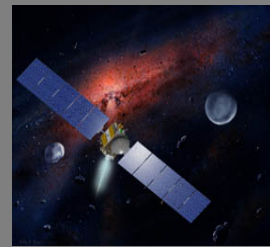
Aquarius



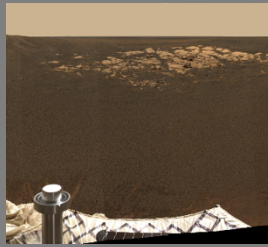
GRACE



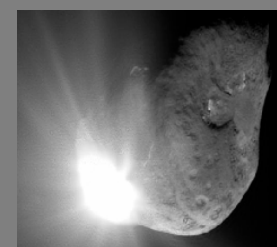
Two Voyagers



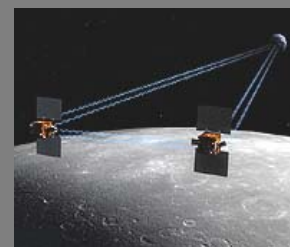
Dawn



Opportunity



EPOXI-Deep Impact



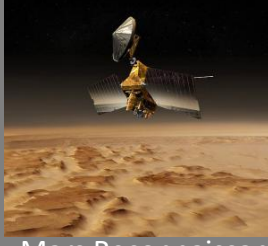
GRAIL



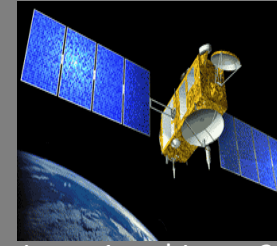
MSL



Wide-field Infrared Survey
Explorer (WISE)



Mars Reconnaissance
Orbiter



Jason 1 and Jason 2

Instruments:

Earth Science

- ASTER
- MISR
- TES
- MLS
- AIRS

Planetary

- MIRO
- Diviner

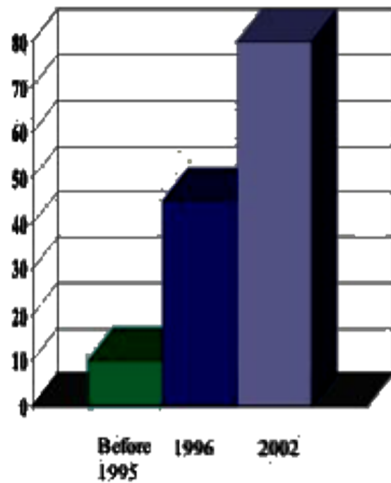
Astrophysics

- Herschel
- Planck

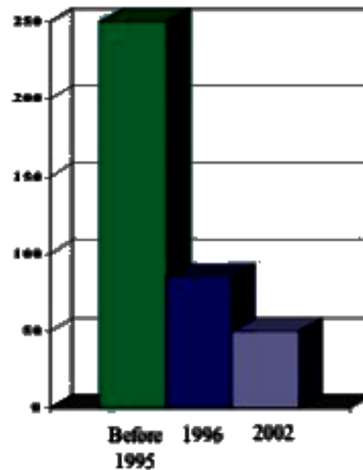
Collaborative Engineering Metrics

CONCEPTUAL DESIGN METRICS

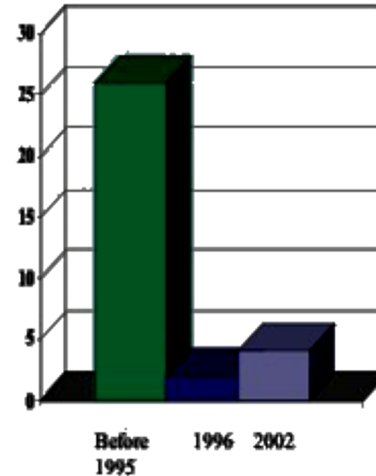
Number of New
Mission Proposals per Year



Typical
Proposal Cost



Typical Concept
Design Time, weeks



Teams can routinely synthesize and cost a design point in a few weeks

Clones now exist in many fields, several countries

- Dedicated Teams
- Scripted Process
- Tailored Information Systems and Facilities
- Broad models
- Distributed Capability



DARPA F6 BAA

- DARPA-BAA-11-01, Tactical Technology Office (TTO) released on October 20, 2010 a Program called System F6 (*Future, Fast, Flexible, Fractionated, Free-Flying Spacecraft United by Information Exchange*). It's goal is to demonstrate the feasibility and benefits of disaggregated—or fractionated—space architectures.
- Key [most important?] feature of Technical Area 1 is *demonstration of new SE/MBE capabilities in both development and acquisition of new systems* which result in “the maturation of a set of design tools that **enable the explicit trade-off between system “–ilities,” such as adaptability and survivability and traditional design attributes, such as size, weight, power, cost, reliability, and performance.**
- This design toolset should help answer two questions.
 - **When does a fractionated architecture make sense?**
 - **When does the business case close?**
- Question answered under *range of uncertainties* including at least: *technology development risks, supply chain delays, changes in user needs, program funding fluctuations, launch failures, component failures, orbital debris, and technological obsolescence.”*

DARPA

- **Defense Advanced Research Projects Agency**
 - “Creating and preventing strategic surprise”
 - www.darpa.mil
- **Brief History of Accomplishments**
 - M16
 - ARPA Net (1973 had 4 nodes) → Internet
 - Stealth Technology
 - GPS
 - Speech Recognition
 - ... many more

ASDA

- ASDA=Adaptable Systems Design and Analysis
- We responded to BAA and proposed to build a tool to not only analyze a fractionated system, but also to design and architect such a system
- Our team is a partnership between JPL and Phoenix Integration
 - We proposed to use computers to automatically generate and evaluate many designs
 - We proposed to provide a GUI to allow users to design:
 - 1) futures, missions, architectures, systems, and
 - 2) their associated parameters
 - Our team “won” the down-select from the Base Period
 - We are now in the middle of the third and final phase

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ASDA Team

- **Jet Propulsion Laboratory:**

- Dr. Brian Bairstow
- Dr. Bjorn Cole
- **Dr. Steven Cornford, PI**
- Dr. Greg Dubos
- Dr. George Fox
- Dr. Steven Jenkins
- Dr. Jonathan Murphy
- Dr. Nicolas Rouquette
- Mr. Tyler Ryan
- Dr. Robert Shishko
- Mr. Stephen Wall
- Mr. Pezhman Zarifian

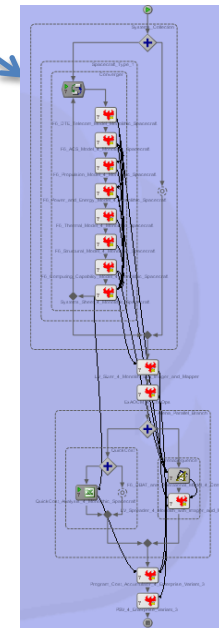
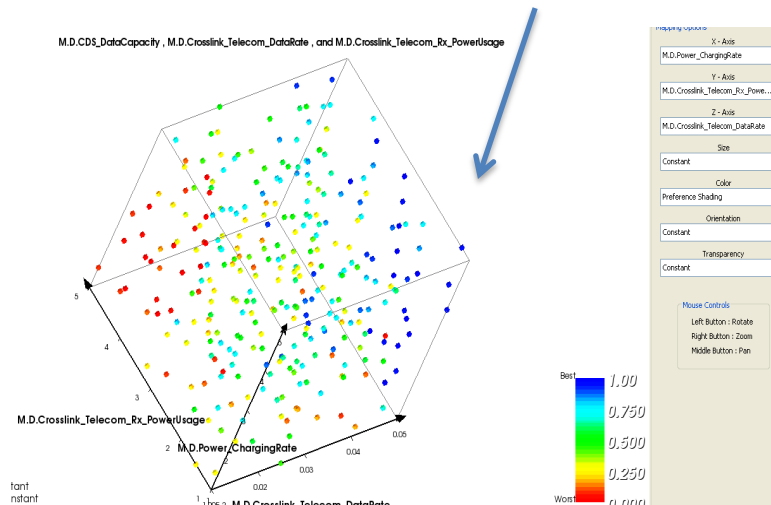
Phoenix Integration

Mr. Justin Boutwell
Mr. Peter Menegay
Mr. Bryce Durham
Mr. Scott Ragon

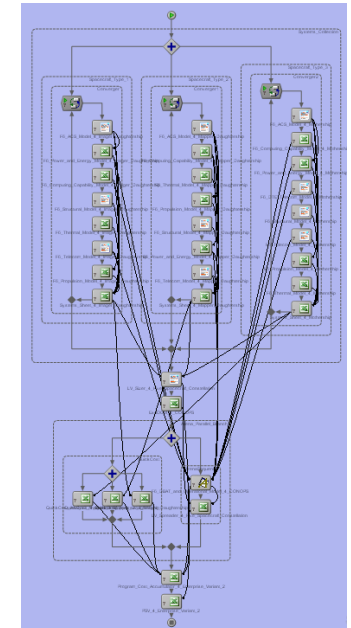
ASDA Results : Brief Summary

- Produced realistic model
 - Included stimuli and responses to measure adaptability and survivability
 - Automatically generated, populated and executed cluster candidates
 - Can Generate populated tradespace with Present Strategic Value as overall metric or other metrics as desired

Scenario Parameter Name	Units	Value
Scenario ID		1
Option Penalty	\$FY11M	\$ 10.00
Ops Cost Multiplier		1.25
Derived Parameter Name	Units	Value
ATP Date		10/1/2012
Payload launch occurred here		7/6/2015
Mothership launch occurred here		1/4/2016
Payload launch occurred here		7/4/2016
Option Purchase Date		6/2/2014
Option Strike Date		7/6/2015
Simulation End Date		9/6/2032
Operating Breakeven Week		619
Discount (Purchase-ATP)		0.948008528
PV_Option (Operating Profit)	\$FY11M	\$ (110.79)
PV_Payload_Delta (DBAT)	\$FY11M	\$ (25.00)
Option Breakeven Draw	\$FY11M	\$ (164.24)
ERO Name	Units	Value
Option to Switch Payloads	\$FY11M	\$ 62.37
"In-the-Money" Probability		0.16



N=1



N=3

ASDA Scope Overview

Implementation and Operations

Mothership j

Daughtership k

Daughtership l

Thinker m

Mothership i

Groundstation

Production lines

Payloads

SC Components

F6 Tech Package

- **Fuel(t)**
- ② • **Power(t)**
- **Data_i(t)**

SCOPE:

- Daughterships
- Motherships
- Thinkers

① Implementation

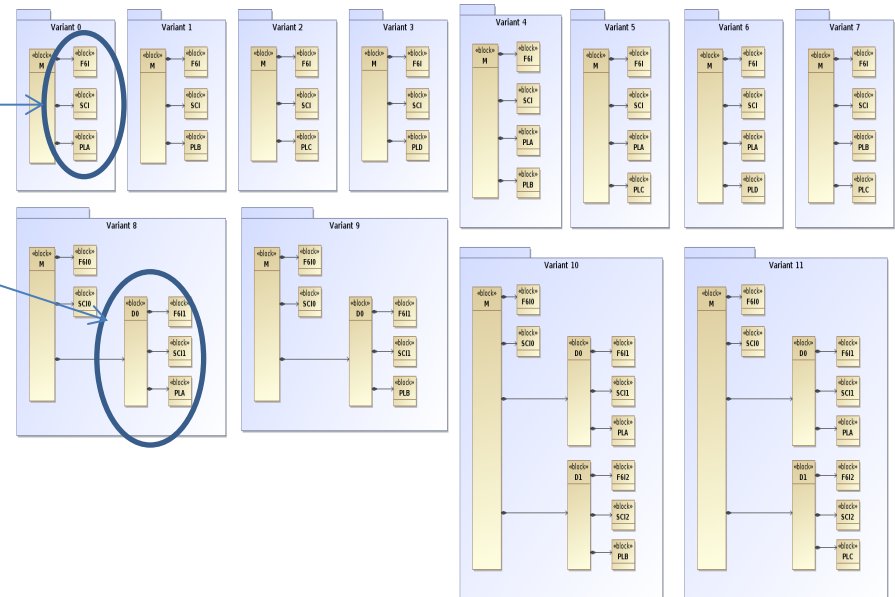
② Operations

+ Stimuli

Architectural Variations

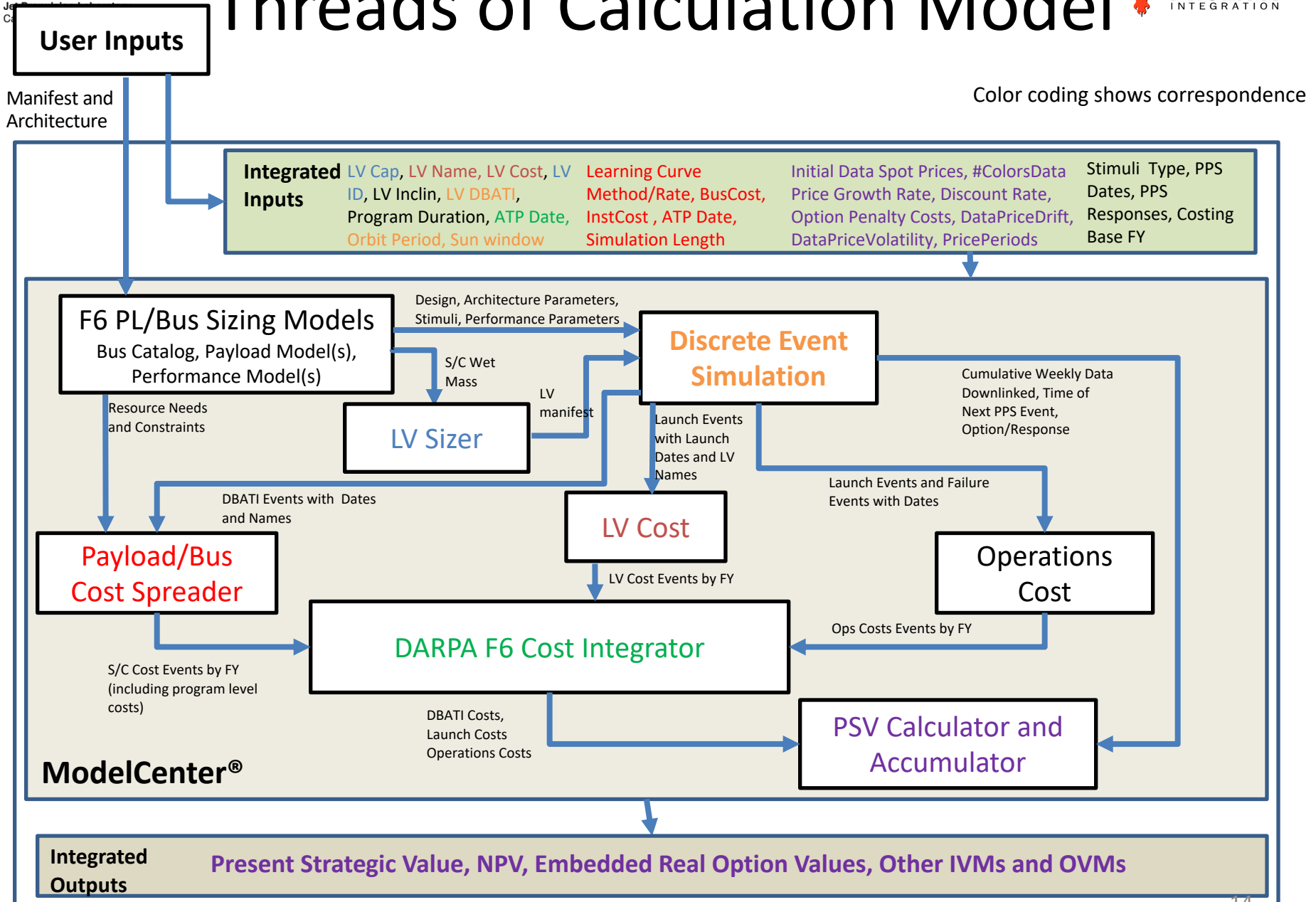
Mothership
(Down-linker)
with 3 payloads

Daughtership
with 3 payloads

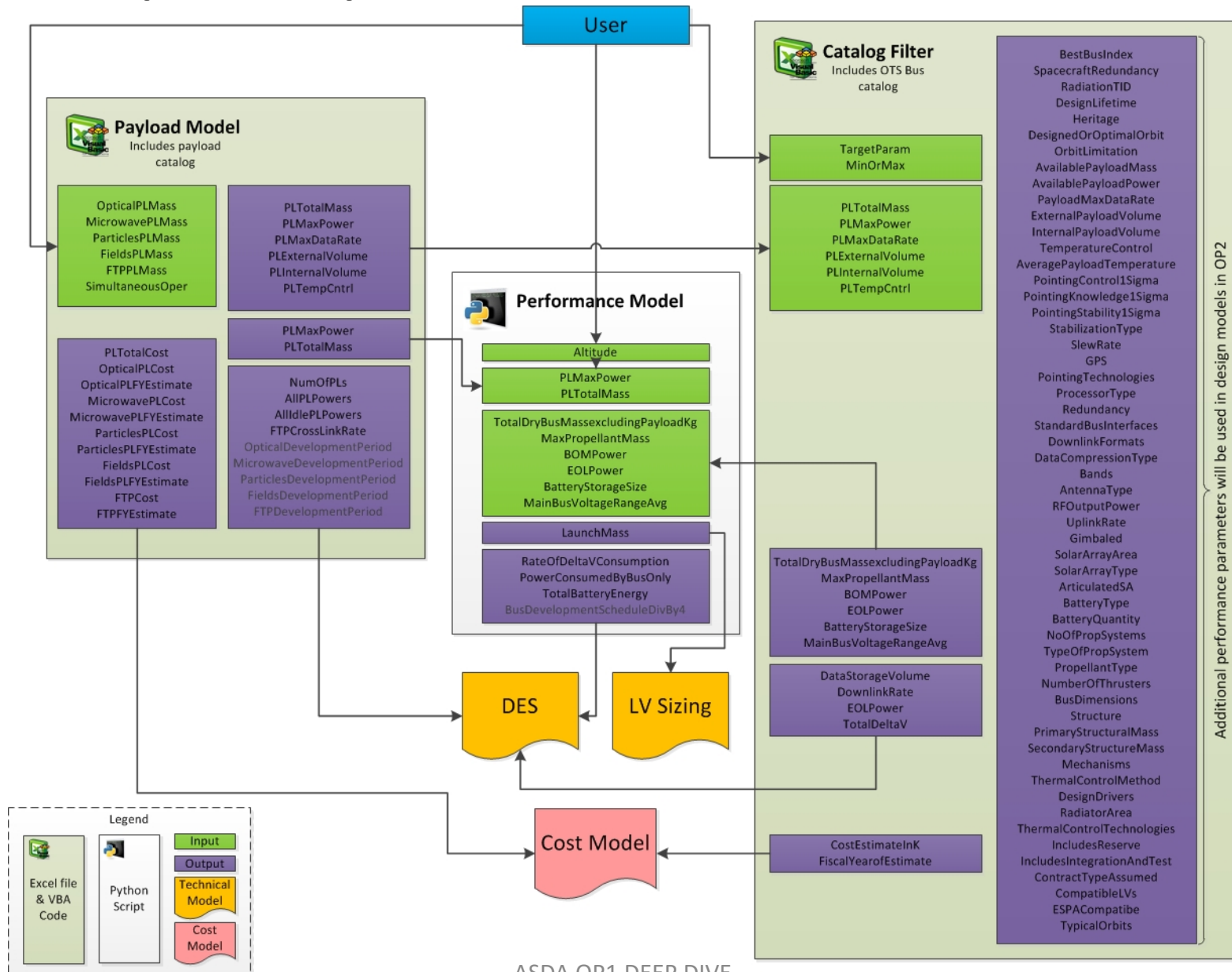


Many architectural combinations:

- # of Spacecraft
 - # of motherships (can downlink)
 - # of daughterships
 - # of thinkers (can process data)
 - →Form a network
- # of Payloads
 - Distribution of those payloads across spacecraft
- # of 'legal' architectures
 - 216 combinations of 3 spacecraft and 4 payloads
 - Gets much, much bigger as the number spacecraft and payloads increase



(some) Parametric Variations

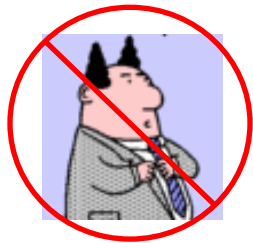


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ModelCenter wraps and is itself wrapped

Architectural-level User

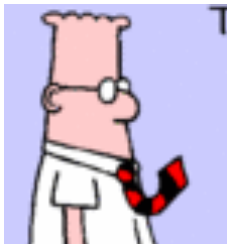


F6
GUI

ModelCenter

MiniZinc

Parametric-level User



ModelCenter

Excel

SimPy

Python

Performed by our team **in advance**

SysML

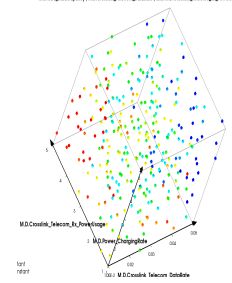
QVTO

MagicDraw

SysML

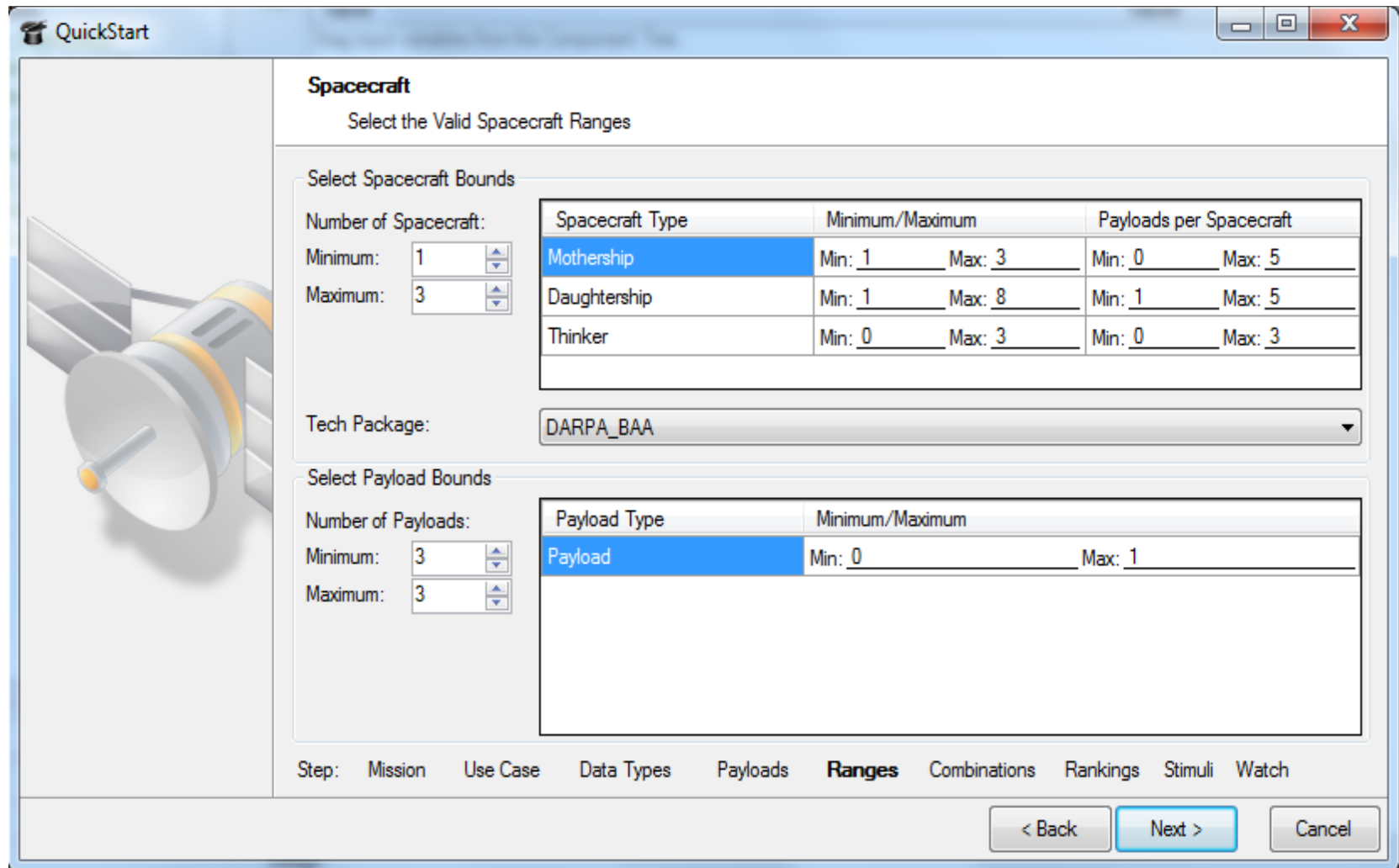
DataExplorer

M3C3L_SimCapacity, M3C3L_SimCapacity, M3C3L_SimCapacity, M3C3L_SimCapacity, M3C3L_SimCapacity



ASDA GUI: “Quickstart”

Provide means for ‘non-expert’ users to be guided thru the model setup/execution process



QuickStart

Spacecraft
Select the Valid Spacecraft Ranges

Select Spacecraft Bounds

Number of Spacecraft:

Minimum:

Maximum:

Spacecraft Type	Minimum/Maximum	Payloads per Spacecraft
Mothership	Min: <input type="text" value="1"/> Max: <input type="text" value="3"/>	Min: <input type="text" value="0"/> Max: <input type="text" value="5"/>
Daughtership	Min: <input type="text" value="1"/> Max: <input type="text" value="8"/>	Min: <input type="text" value="1"/> Max: <input type="text" value="5"/>
Thinker	Min: <input type="text" value="0"/> Max: <input type="text" value="3"/>	Min: <input type="text" value="0"/> Max: <input type="text" value="3"/>

Tech Package:

Select Payload Bounds

Number of Payloads:

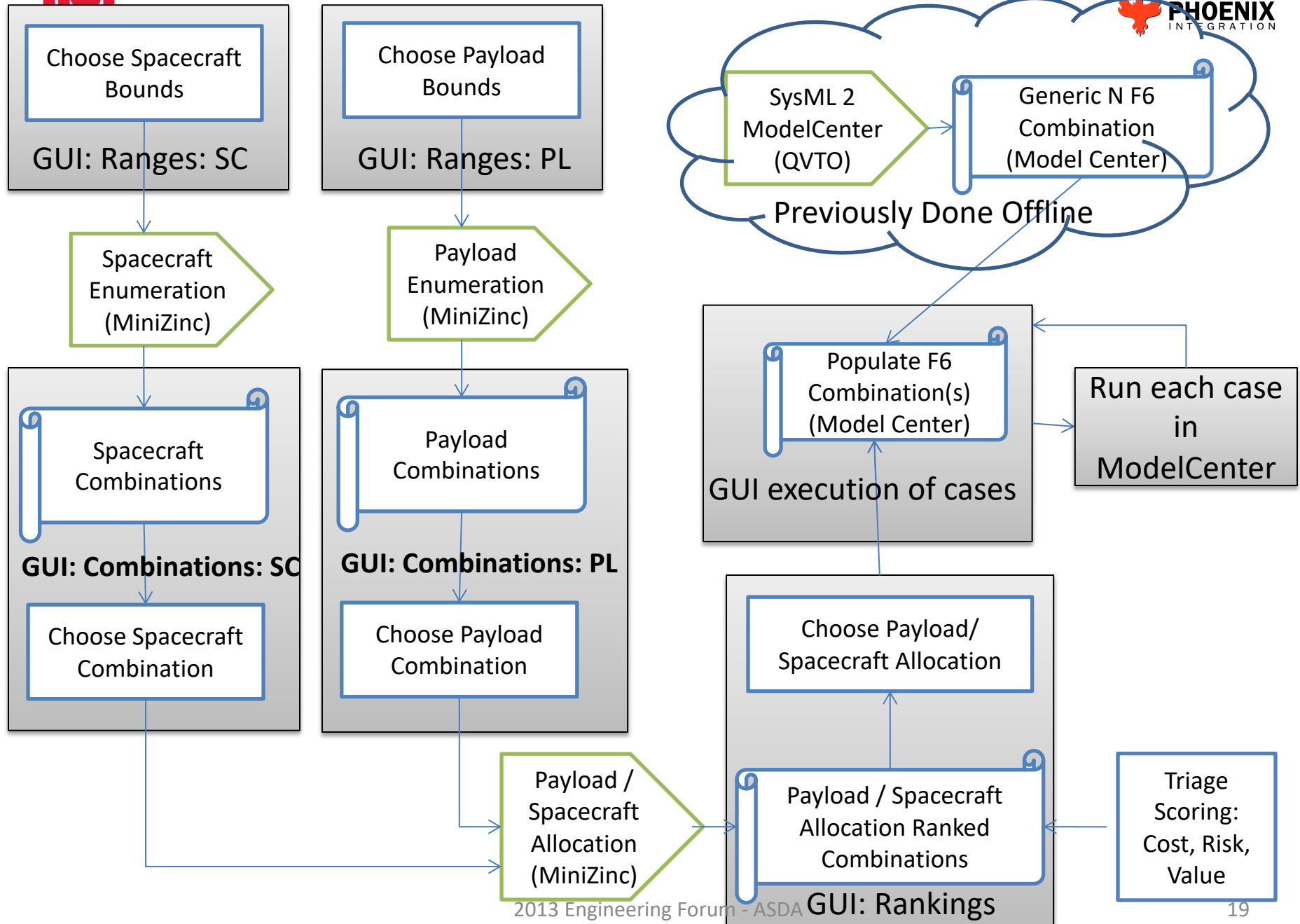
Minimum:

Maximum:

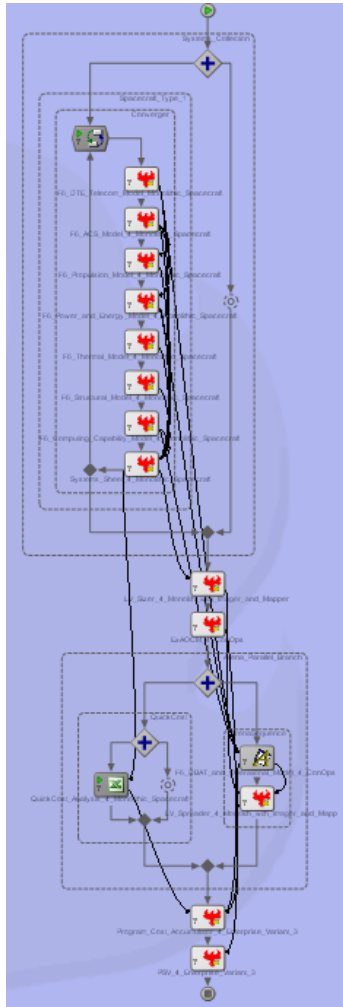
Payload Type	Minimum/Maximum
Payload	Min: <input type="text" value="0"/> Max: <input type="text" value="1"/>

Step: Mission Use Case Data Types Payloads **Ranges** Combinations Rankings Stimuli Watch

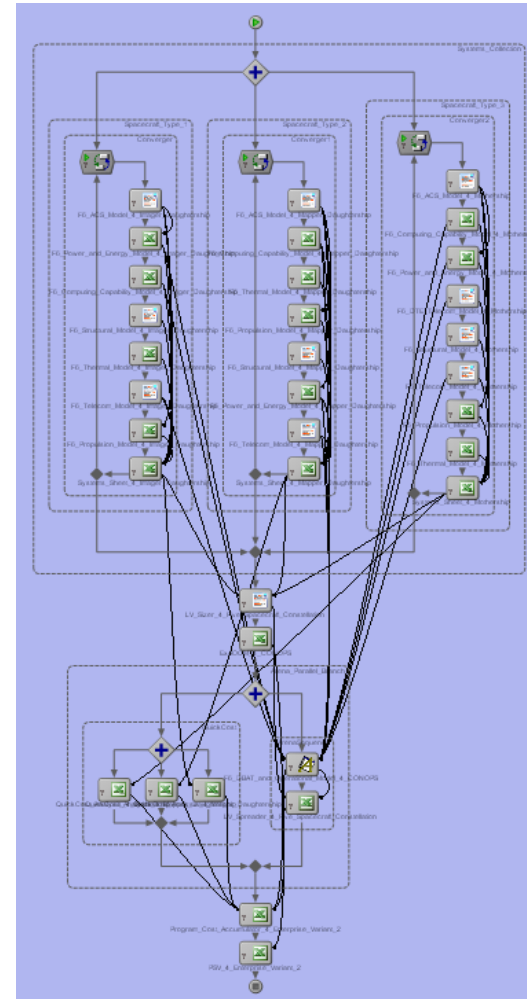
< Back Next > Cancel



Examples of automatically generated Executable Model(s) in ModelCenter



Monolith



3 Module Cluster

AGENDA

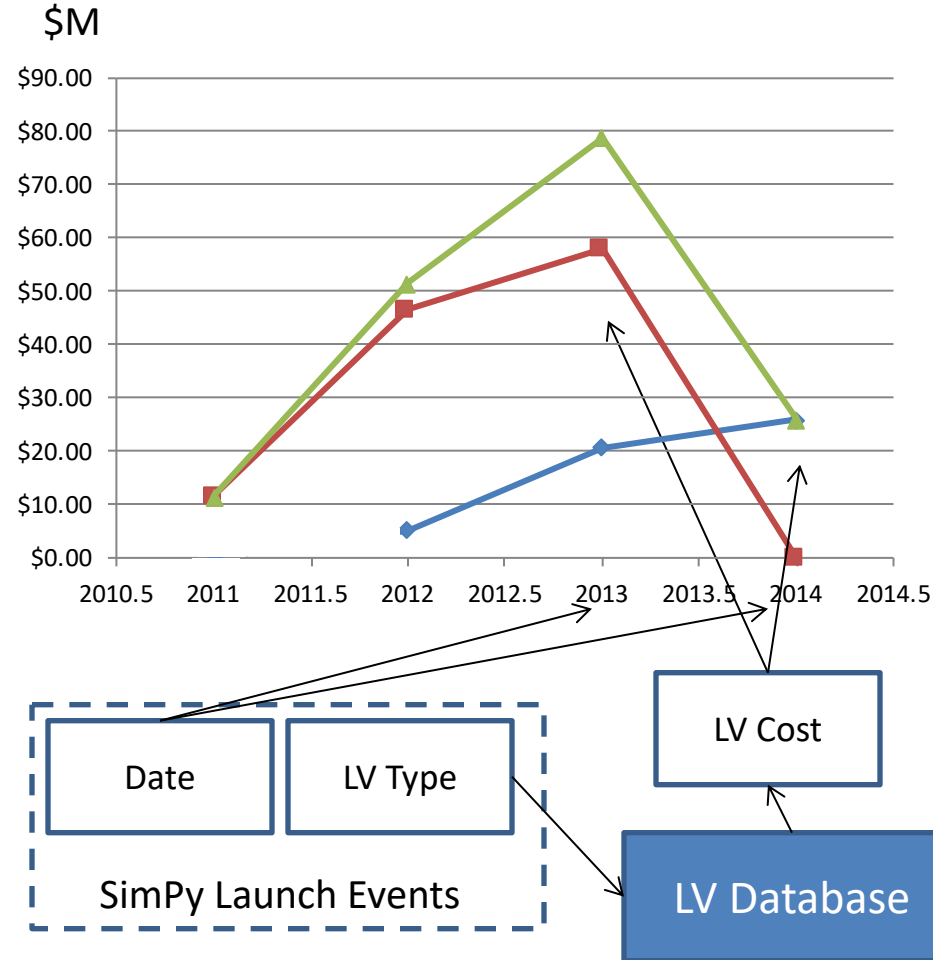
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SC, LV and PL Catalogs

- Started with Design Models
 - From standard Spacecraft Engineering information
 - Populated with open-source, generic data
 - Loops for sizing propulsion, thermal, etc.
 - Used various available public cost models
 - Was realistic but...
 - run times were longer,
 - costs were tougher to estimate,
 - and results meant everything would be ‘custom’
- Switched to Catalog approach
 - Spacecraft (SC) from JPL internal data (58 parameters)
 - Launch Vehicles (LV) for open source data (7 parameters)
 - Payloads (PL) from NASA Instrument Cost Model (NICM) (6 parameters)

Catalogs and costing

Example: LV Cost Model



Launch costs are spread over
phases of production process.

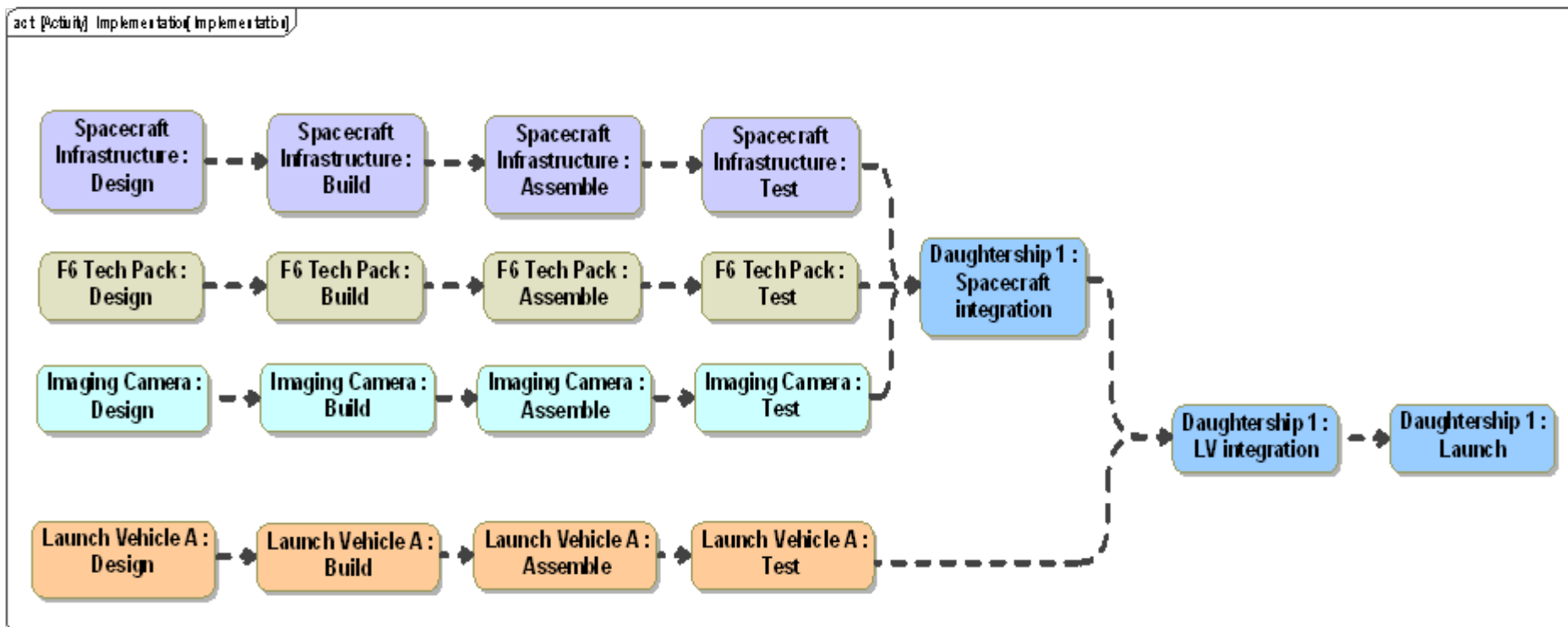
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F6 DES Model overview

Implementation Phase

- Spacecraft subassemblies developed in parallel on distinct production lines, following “Design, Build, Assembly, Test and Integration” (DBATI) sequence

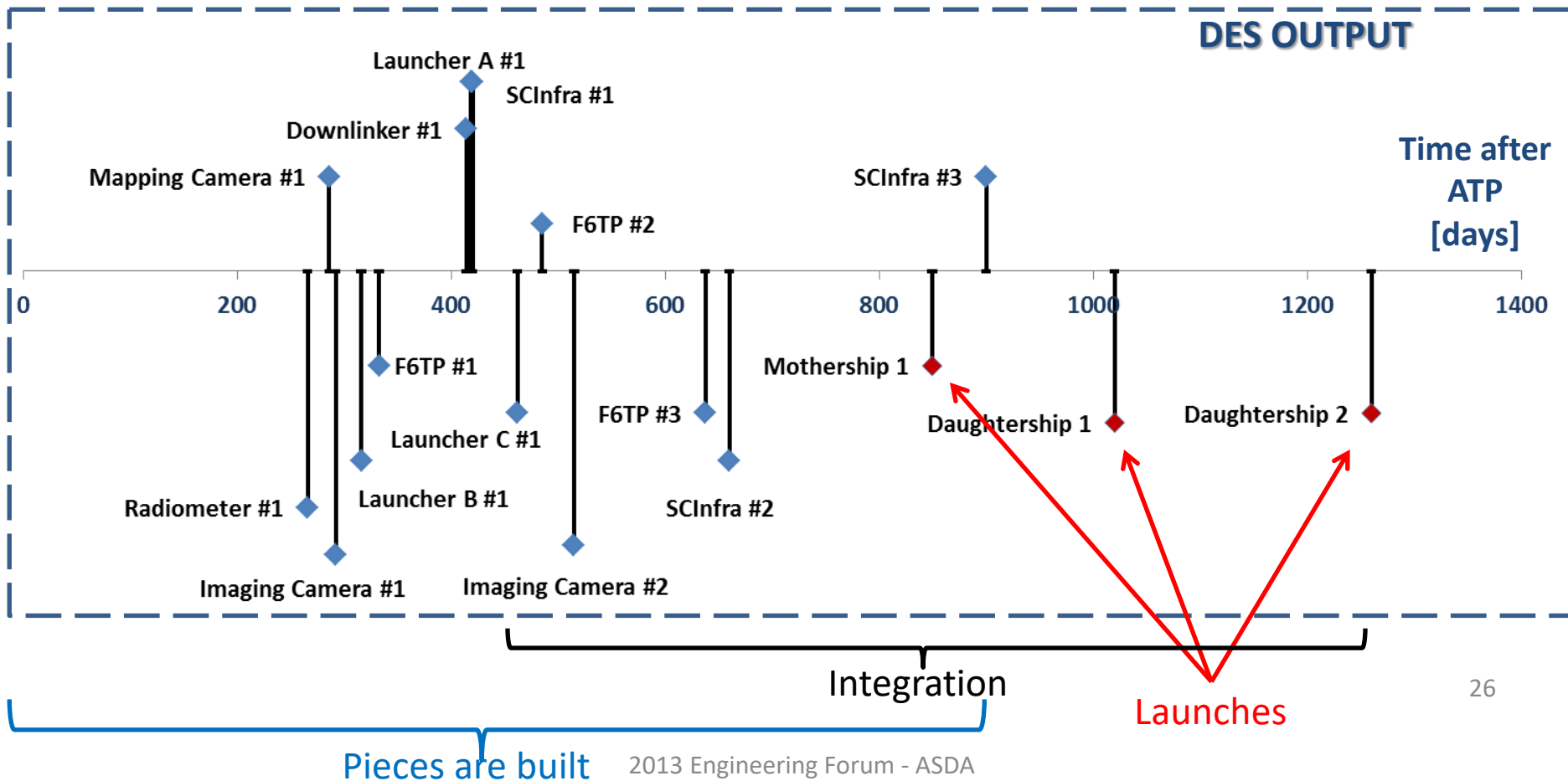


Discrete Event Simulator Example

Mothership [1]: F6TP, Downlinker, Spacecraft

Daughtership [1]: F6TP, Imaging Camera, Mapping Camera, Spacecraft

Daughtership [2]: F6TP, Imaging Camera, Radiometer, Spacecraft



DES Example (cont.)

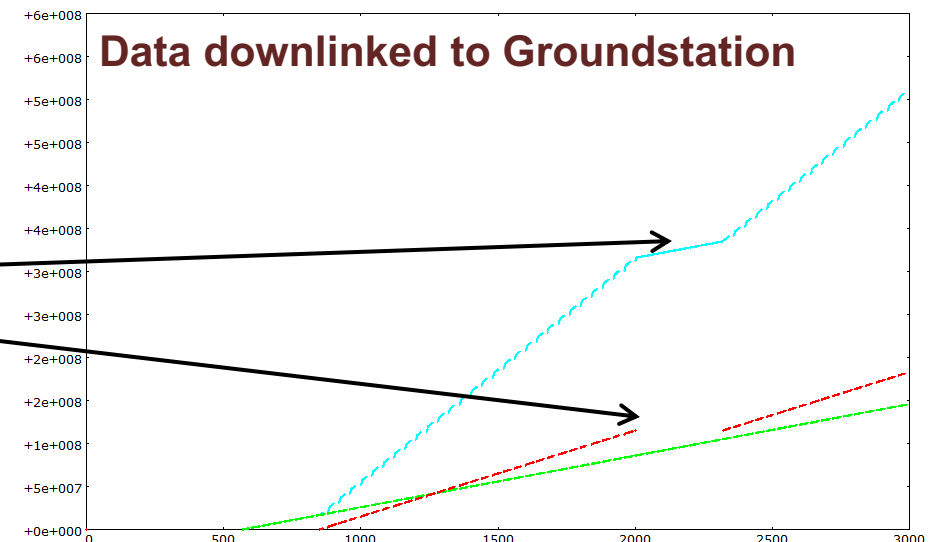
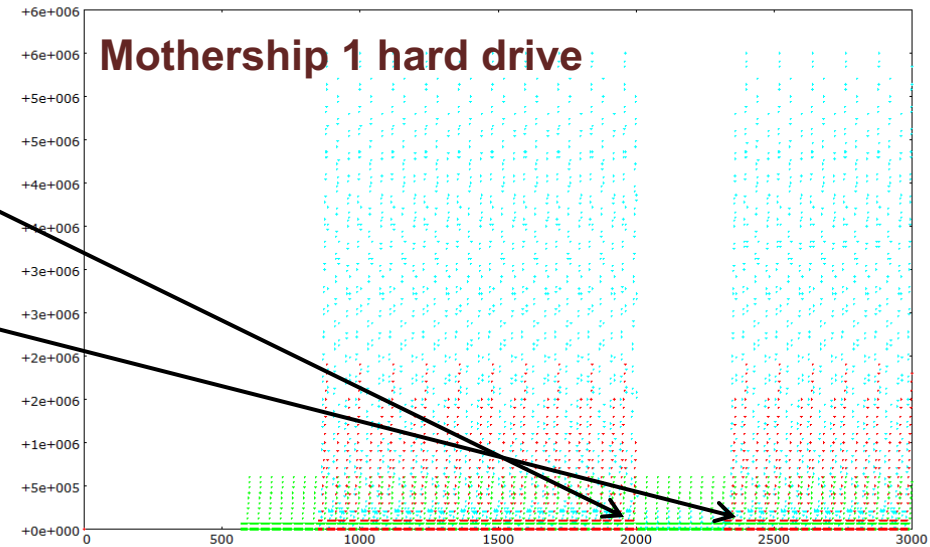
Scenario: On-Orbit Failure

Daughtership 1 Total Failure,
“*Replace spacecraft*” option exercised

Replacement Daughtership launched

Consequences:

Reduction in incoming data



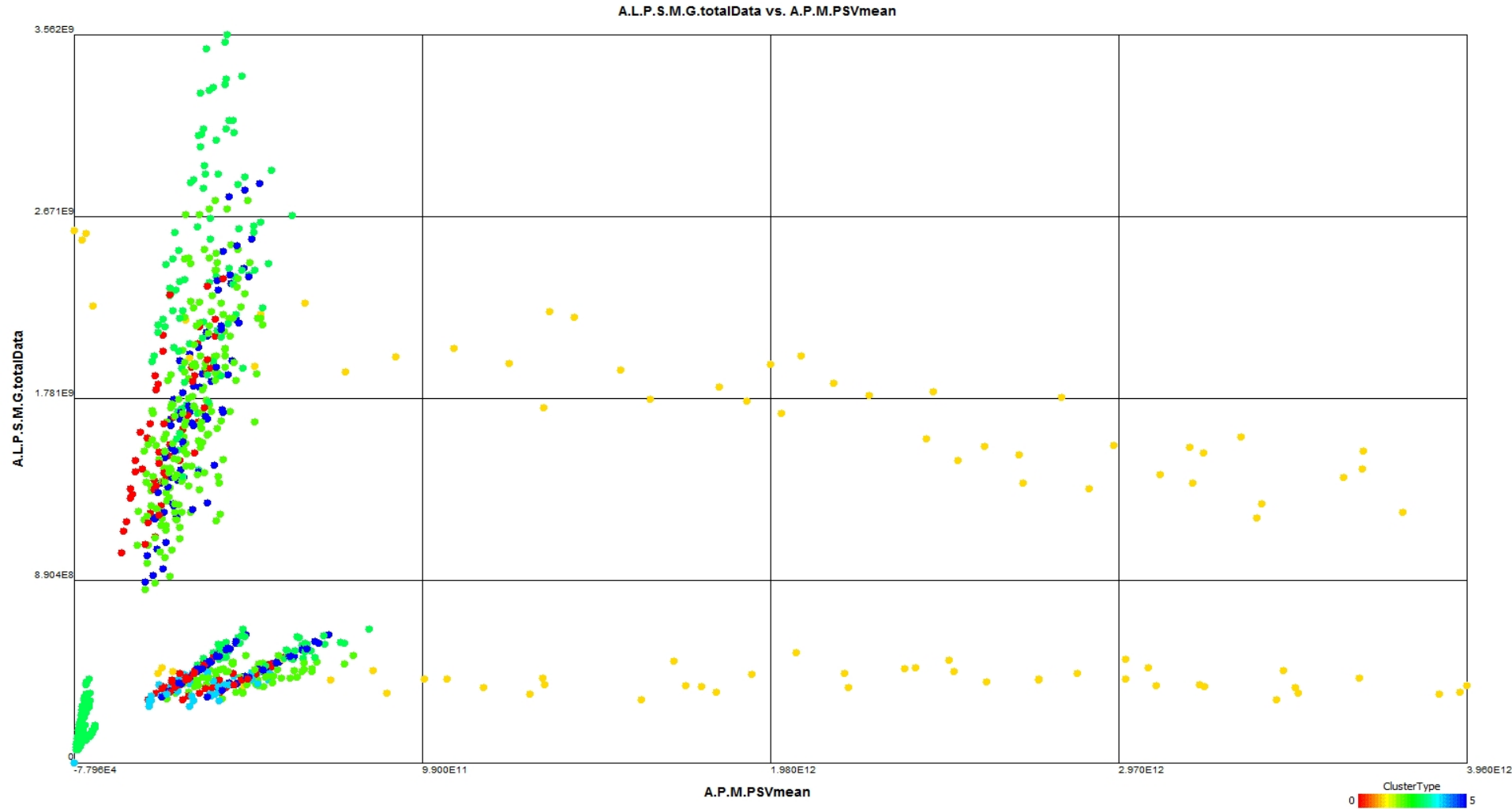
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Preliminary Case Study

- Orbital Debris
 - Debris event at around halfway point of mission
 - Vary the size and type of payloads
 - Vary the constellation (e.g. # MS, #DS)
 - Vary the assumed victim
 - Vary the distribution of payloads
 - Note 1 MS means only one way to downlink

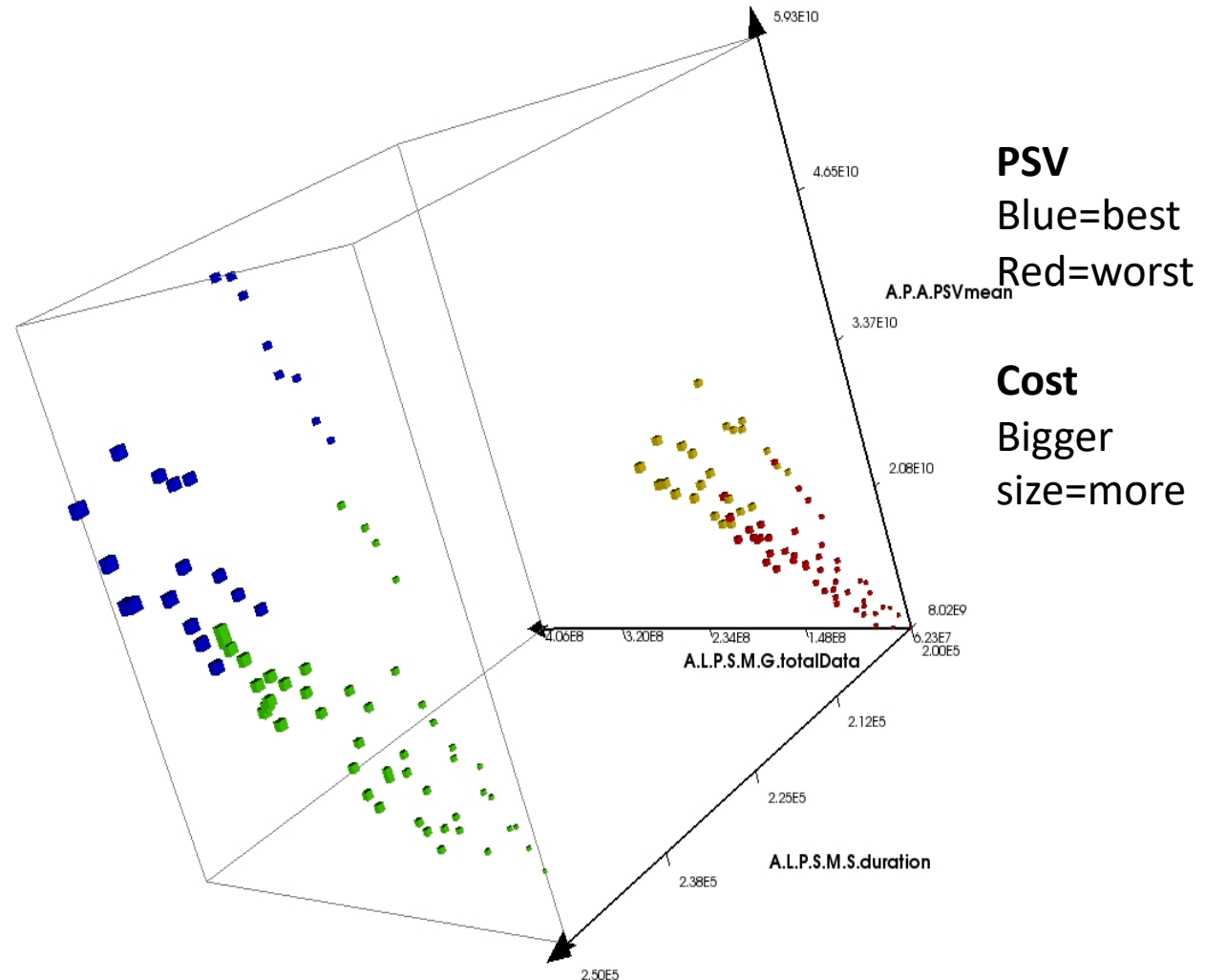
Preliminary Debris Study: Results



Yellow,Red=1MS1DS, Green,Blue=1MS2DS, lightBlue=1MS

Preliminary Debris Study: Results

A.L.P.A.I.S.O.V.name(0) , A.L.P.P.A.MicrowavePLMass , and A.L.P.P.P.FieldsPLMass



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Wrap-up

- Provided brief summary of the JPL/Phoenix Integration team product for the DARPA System F6 Program
- Tool is available for others to use
 - Still working on one remaining Export Control issue before general release
- Utilizing some of the power of MBSE
 - Single source of data
 - Transformations of base model to specific models
 - Framework in place, allow users to customize data contents
 - Domain experts can visualize relevant subsets
 - Strong enabling of collaborative design in architectural phase
 - Can (easily) modify for other applications

Plans for this last Option Period

- Get the tool deployed
 - Improve the GUI
 - Verify and Validate
 - Perform case studies
 - Perform Pilot applications
 - Get the word out
 - Develop and Implement training sessions and materials
 - Provide insight into to how to customize
- Upgrade F6 Trade tool as needed
 - Features that are necessary for infusion
 - For design/trades
 - For ease of use
 - Bugs as discovered

Obtaining the F6 Design Tool

- 1) Interested party is sent a link to the F6 Design Tool submission form; http://www.phoenix-int.com/f6dk_request.php.
- 2) After submitting, F6 ASDA team leadership (Steve Cornford and Peter Menegay) will receive the request via an automated email.
- 3) The requester is sent a reply, either a rejection, or a request for the necessary information to Phoenix Integration to respond with appropriate licenses and download account information.
- 4) When the requested information is received, Phoenix Integration will create the needed ModelCenter and Analysis Server license files, and provide a download link with a download account that has all necessary files, including a word document.
 - Downloads link: <https://analysislibrary.phoenix-int.com/content/files/Groups/F6DK/Downloads/>
 - Instructions file: [F6DK Installation Instructions.docx](#)
- 5) Support is provided as needed.

BACKUP

Uncertainties with Candidate Embedded Adaptability and Survivability Real Options

Adaptability

Uncertainty Type	Embedded Real Options
Technology Development Risk	Option to Switch Technologies Option to Suspend/Slow Ancillary Developments
Supply Chain Delays	Option to Switch Payloads Option to Switch Technologies Option to Suspend/Slow Ancillary Developments
Changes in User Needs	Option to Switch Payloads Option to Discontinue Option to Abandon Option to Expand Option to Accelerate Development Option to Switch Technologies
Program Funding Fluctuations	Option to Defer Development Option to Accelerate Development Option to Expand Option to Delay Launch Option to Suspend Ancillary Development Option to Switch Technologies Option to Switch Payloads Option to Discontinue Option to Abandon
Technology Obsolescence	Option to Abandon Option to Switch Technologies Option to Discontinue Option to Accelerate Development Option to Switch Payloads

Survivability

Uncertainty Type	Embedded Real Options
Launch Failure	Option to Accelerate Development
Operator Failure	Option to Accelerate Development Option to Not Replace
Component Failure	Option to Accelerate Development Option to Not Replace
Orbital Debris	Option to Accelerate Development Option to Not Replace
Space Weather	Option to Accelerate Development Option to Not Replace
Collision	Option to Accelerate Development Option to Not Replace
Cyber Security	Option to Discontinue Option to Abandon Option to Not Replace Option to Switch Technologies Option to Accelerate Development



Currently in ASDA model

Present Strategic Value (PSV) of an Investment (ala Schwartz and Trigeorgis, et al.*)

$$PSV = E_p[NPV] + \text{Value of Embedded Real Options}$$

- **General Nature of Embedded Real Options (EROs)**
 - Expand, Contract
 - Defer, Accelerate
 - Switch (Repurpose, Abandon)
- **Practical Implementation Issues**
 - Consistently calculating each real option value
 - Embedding them in a lengthy, complex project
 - PSV depends on the assumed PPS and parameters of each ERO
 - Creating the Threads of Calculation
 - Inputs
 - Models needed/available

*Eduardo S. Schwartz and Lenos Trigeorgis, eds., *Real Options and Investment Under Uncertainty*, 2001, MIT Press, Cambridge, MA

GUI Tabs

- Mission – basic mission/economic parameters
- Use Case – drives some of the subsequent tabs
 - Range of Clusters: Specific Payloads
 - Range of Clusters: N Generic Payloads
 - Single Cluster Topology
- Data Types – define color, prices (initial, volatility, drift)
- Payloads – type, mass, color
- Ranges – Spacecraft and Payloads: minimums, maximums and ranges
- Combinations – Results of architectural exploration
- Rankings – based on simple “triage”
- Stimuli – User selects futures, associated parameters
- Watch – User selects variables to monitor/measure

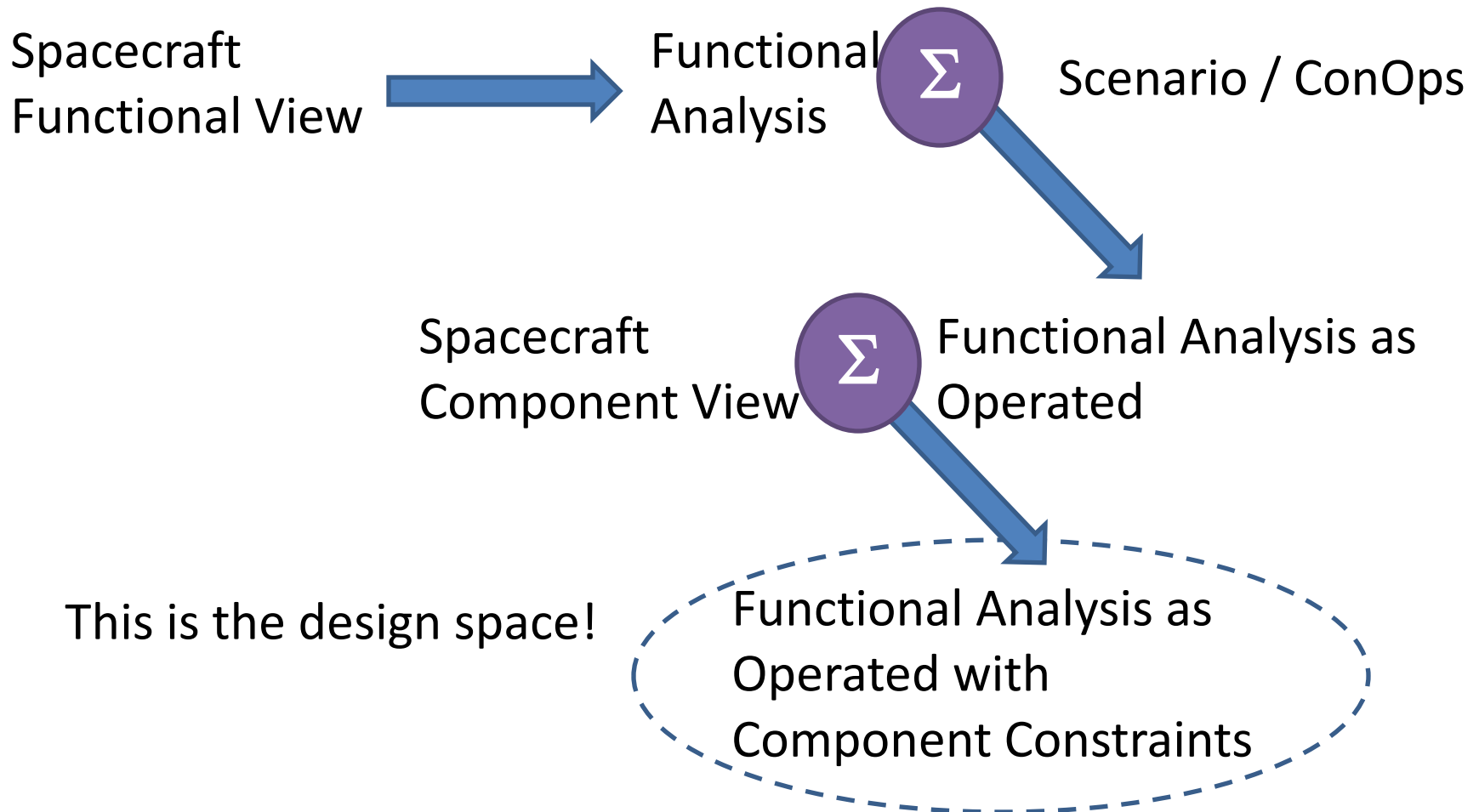
Notes

- We have various spacecraft and payload databases which can be *repopulated with particular user data*
- We can have many data types
 - Representing customers, instrument type, classification levels
- We can have multiple ground stations which can be selected for various data types
- We can simulate monolith, disaggregation and fractionation
 - User can select cluster/network topology
 - Motherships can downlink
 - Daughterships can only cross link
 - Thinkers can only process cross-linked data and then cross-link that 'new' data
 - User can distribute payloads across various spacecraft in the cluster
 - Could be F6-type cluster with motherships/daughterships/thinkers
 - Could be single monolith
 - Could be sequenced monoliths
 - Could be wireless-enabled monoliths with possible future extension to daughterships
 - Or various combinations of above

Cost Modeling

- Spacecraft (SC) and Payload (PL) databases
 - Provides total cost and duration for builds
 - Break down into different phases and distribute cost
 - Design, Build, Assemble, Test and Integration (PL and LV)
 - Learning curves
- Small Spacecraft Cost Model
 - ASDA model provides some input values
 - User can provide rest of required inputs
 - Costs generated from that
 - Proposed to put “hooks” to model and let users get their own copy from Aerospace (Currently being worked with Aerospace)

The Power Of Model Transformation



ASDA hard choices

- DARPA Requirements: a) Model wide variety of use cases (vary SC, PL, stimuli and connections), b) be open source, c) require minimal training
- Case 1:
 - Buy MagicDraw (\$), QVTO (with JPL enhancements) (t)
 - Train SysML, QVT experts (t, \$)
 - Produce: Anything you want
 - Cons: t, \$, violates b), tough on c)
- Case 2:
 - Use machinery of Case 1 to make all combinations (SC, PL, stimuli, and connections) ahead of time.
 - Cons: TB of download files, tough on b) and c)
- Case 3
 - Build “superset” model which can replicate all combinations (SC, PL, stimuli and connections) on the fly
 - Cons: Difficult to modify, meets a) - c)

Payload Catalog

“Realistic” Data: Taken from NASA Instrument Cost Model (NICM), ‘sanitized’ and curve fit

Type	Mass (kg)	Power (J/min)	Design Life (months)	Data Rate (kbpm)	External Volume (m ³)	Internal Volume (m ³)	Temp Control?	Instrument TRL	Cost 50% (\$K)	FY Estimate
Optical	10	600	60	360	0.010	0.003	N	7	8270	2004
Optical	25	1500	60	720	0.025	0.007	N	7	16338	2004
Optical	50	3000	60	1140	0.050	0.013	N	7	27362	2004
Optical	75	4500	60	1560	0.075	0.019	Y	7	37004	2004
Optical	100	6000	60	1920	0.100	0.025	Y	7	45846	2004
Optical	150	9000	60	2580	0.150	0.038	Y	7	62016	2004
Optical	250	15000	60	3780	0.250	0.063	Y	7	90762	2004
Optical	350	21000	60	4860	0.350	0.088	Y	7	116654	2004
Microwave	10	600	60	360	0.010	0.003	N	7	11253	2004
Microwave	25	1500	60	720	0.025	0.007	N	7	20744	2004
Microwave	50	3000	60	1140	0.050	0.013	N	7	32964	2004
Microwave	75	4500	60	1560	0.075	0.019	Y	7	43230	2004
Microwave	100	6000	60	1920	0.100	0.025	Y	7	52399	2004
Microwave	200	12000	60	3240	0.200	0.050	Y	7	83336	2004
Microwave	300	18000	60	4380	0.300	0.075	Y	7	109332	2004
Microwave	400	24000	60	5400	0.400	0.100	Y	7	132561	2004
Microwave	500	30000	60	6360	0.500	0.125	Y	7	153942	2004
Particles	1	60	60	60	0.001	0.001	N	7	1663	2004
Particles	5	300	60	240	0.005	0.002	N	7	6550	2004
Particles	10	600	60	360	0.010	0.003	N	7	11821	2004
Particles	20	1200	60	600	0.020	0.005	N	7	21336	2004
Particles	40	2400	60	960	0.040	0.010	N	7	38507	2004
Fields	1	60	60	60	0.001	0.001	N	7	2927	2004
Fields	5	300	60	240	0.005	0.002	N	7	5770	2004
Fields	10	600	60	360	0.010	0.003	N	7	7730	2004
Fields	15	900	60	480	0.015	0.004	N	7	9172	2004
Fields	25	1500	60	720	0.025	0.007	N	7	11377	2004

SC Catalog

“Realistic Data” - ‘sanitized’ JPL Internal Data

Total Dry Bus Mass excluding Payload (kg)	Redundancy (hot, cold, dual, single string)	Total Delta V (m/s)
Spacecraft Redundancy (Single, Dual, Selective, etc)	IEEE-1394, etc.)	Propellant Type (name/description)
Radiation TID (krad)	Downlink Formats (CCSDS, STDN, etc)	Max Propellant Mass(es) (kg)
Design Lifetime (months)	Data Compression (type)	Number of Thrusters (#)
Heritage (description)	Data Storage Volume (kb)	Bus Dimensions (m)
Designed/Optimal orbit (type)	Bands (name)	Structure (shape/description)
Orbit Limitation (description)	Antenna Type, size, & number (description)	Primary Structural Mass (kg)
Available Payload Mass (kg)	RF Output Power (W)	Secondary Structure Mass (kg)
Available Payload Power (J/min)	Uplink Rate (kbps)	Mechanisms (type, quantity)
Payload Max Data Rate (kbpm)	Downlink Rate (kbpm)	Thermal Control Method (description)
External Payload Volume (m ³)	Gimbaled? (Y/N)	Design Drivers
Internal Payload Volume (m ³)	BOM Power (J/min)	Radiator Area (m ²)
Temperature Control? (Y/N)	EOL Power (J/min)	(description)
Average Payload Temperature (K)	Solar Array Area (m ²)	Cost Estimate (\$K)
Pointing Control - 1 Sigma (arcsec)	Solar Array Type (description)	Includes Reserve? (Y/N)
Pointing Knowledge - 1 Sigma (arcsec)	Articulated SA? (Y/N)	Includes I&T? (Y/N)
Pointing Stability - 1 Sigma (arcsec/s)	Battery Storage Size(s) (A-hrs)	Fiscal Year of Estimate (YYYY)
Stabilization Type (3-axis, spin stabilized, gravity gradient, etc)	Battery Type(s) (description)	Contract type assumed (type/description)
Slew Rate (deg/min)	Battery Quantity (#)	Compatible LVs (names)
GPS (Y/N)	Main Bus Voltage Range Avg (V)	ESPA-Compatible?
Pointing Technologies (description)	No. of Prop Systems (#)	Typical Orbits (LEO, MEO, GEO, and/or Other)
Processor Type (name/description)	Type(s) of System(s) (description)	Bus Development Schedule (min)

SC Catalog Parameters

SSCM in ASDA

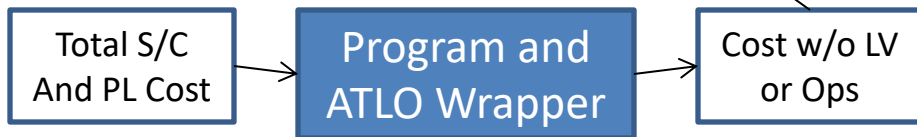
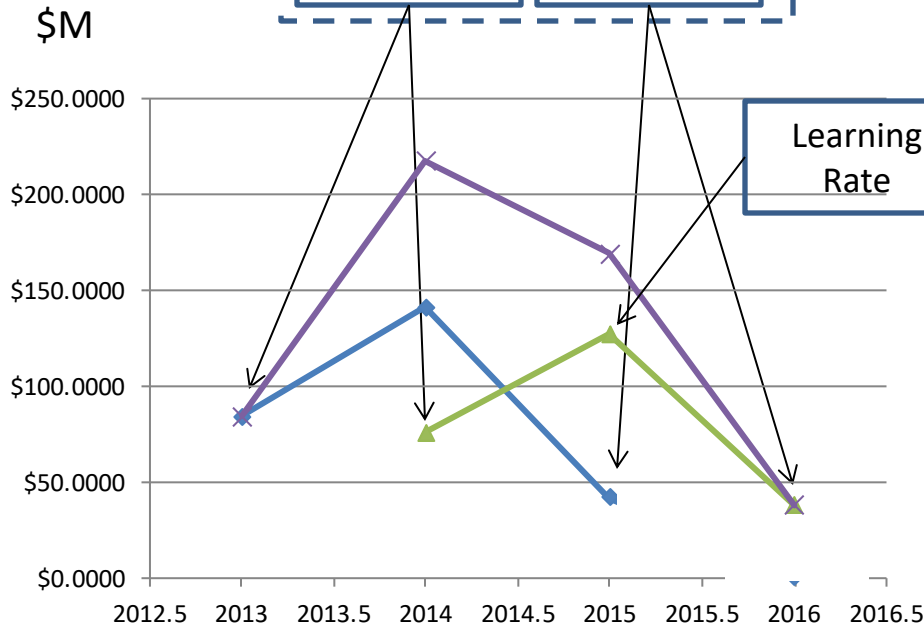
Trying to work two issues: 1) what can we 'open source', and 2) can it be run in batch mode

Input	Units	Options		
Development Time	months			
Destination		Earth-Orbiting	Planetary	
Satellite Wet Mass	kg			
Spacecraft Bus Dry Mass	kg			
Number of Instruments				
Solar Array Mounting Type		Body-Mounted	Deployed - Fixed	Deployed - Sun-Pointing
Solar Cell Type		Silicon	Galium Arsenide	
Battery Type		NiCd	NiH2	
Power Subsystem Mass	kg			
BOL Power	W			
Primary Structure Material		Aluminum	Composite	
Structure Subsystem Mass	kg			
Stabilization Type		Spin	3-axis	
Star Tracker		Yes	No	
ADCS Subsystem Mass	kg			
Pointing Control	deg			
Propellant Type		Cold Gas	Hydrazine	
Propulsion Type		Monoprop	Biprop	
Propulsion Subsystem Dry Mass	kg			
Communications Band		UHF/VHF	S-Band	
TT&C/C&DH Subsystem Mass	kg			
Transmit Power	W			
Thermal Subsystem Mass	kg			
		LEGEND	Already output	In Bus Catalog
				Not in Bus Catalog

This information is Export Controlled – Not for External Release

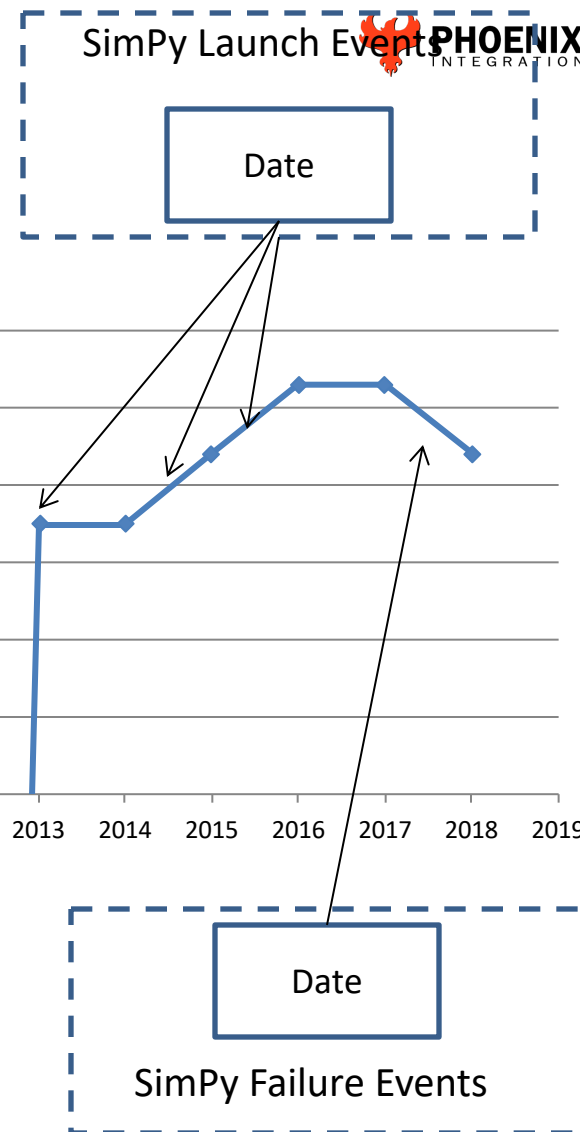
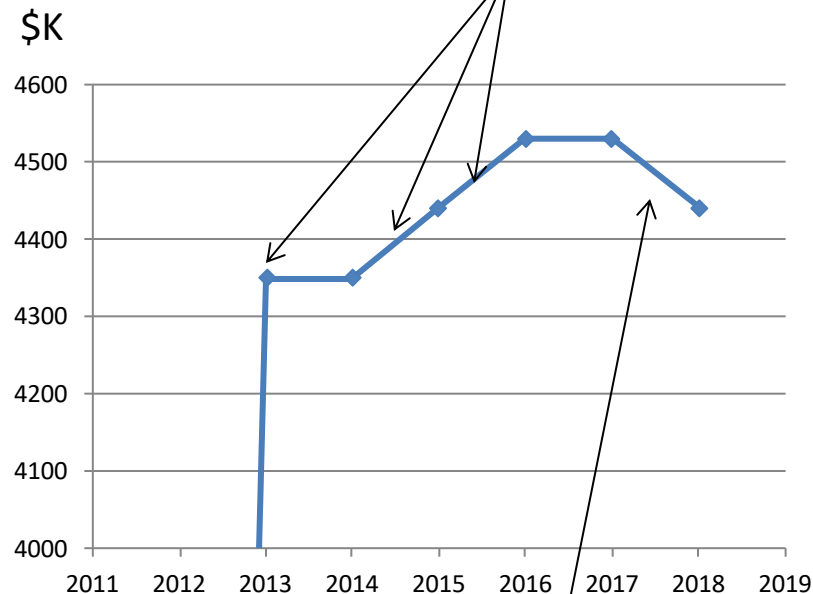
2013 Engineering Forum - ASDA

S/C and PL Cost Model



Bus and payload catalog costs are wrapped and spread over phases, and learning rates are applied.

Ops Cost Model



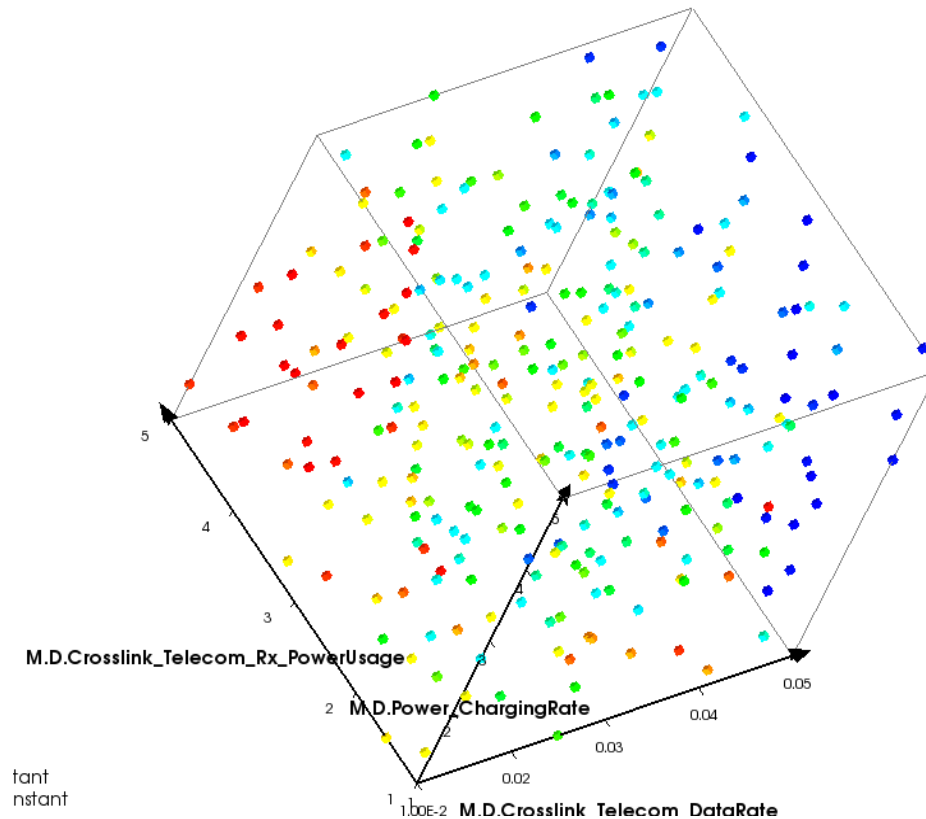
Launch events increase # S/C to operate, failure events decrease # S/C to operate. # S/C -> # FTE -> Cost

Preliminary Case Study

- Orbital Debris
 - Debris event at around halfway point of mission
 - Vary the size and type of payloads
 - Vary the constellation (e.g. # MS, #DS)
 - Vary the assumed victim
 - Vary the distribution of payloads
 - Note 1 MS means only one way to downlink

Sample Output

M.D.CDS_DataCapacity , M.D.Crosslink_Telecom_DataRate , and M.D.Crosslink_Telecom_Rx_PowerUsage



Mapping Options

X - Axis
M.D.Power_ChargingRate

Y - Axis
M.D.Crosslink_Telecom_Rx_Powe...

Z - Axis
M.D.Crosslink_Telecom_DataRate

Size
Constant

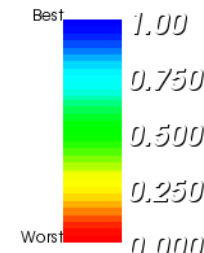
Color
Preference Shading

Orientation
Constant

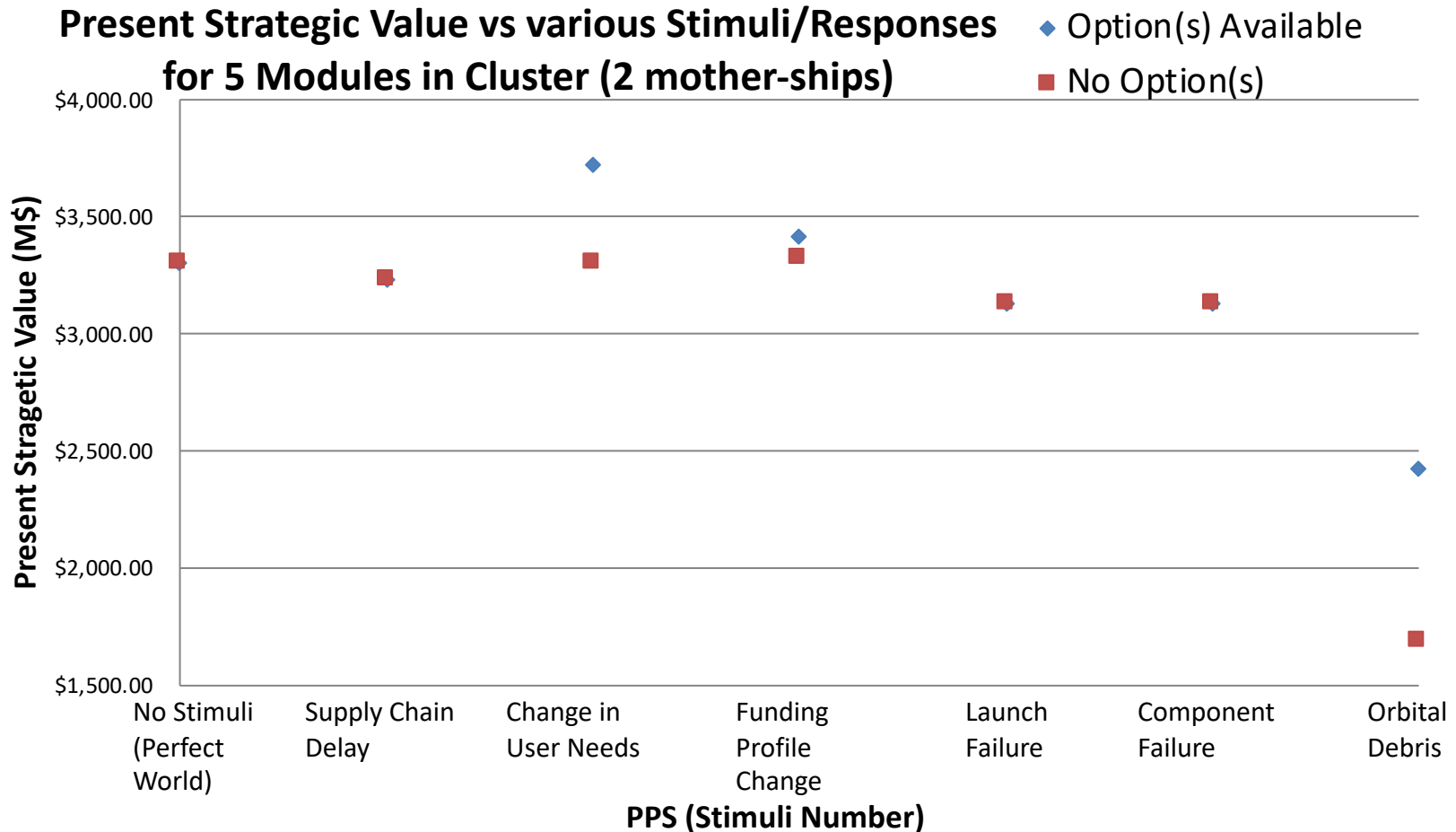
Transparency
Constant

Mouse Controls

Left Button : Rotate
Right Button : Zoom
Middle Button : Pan

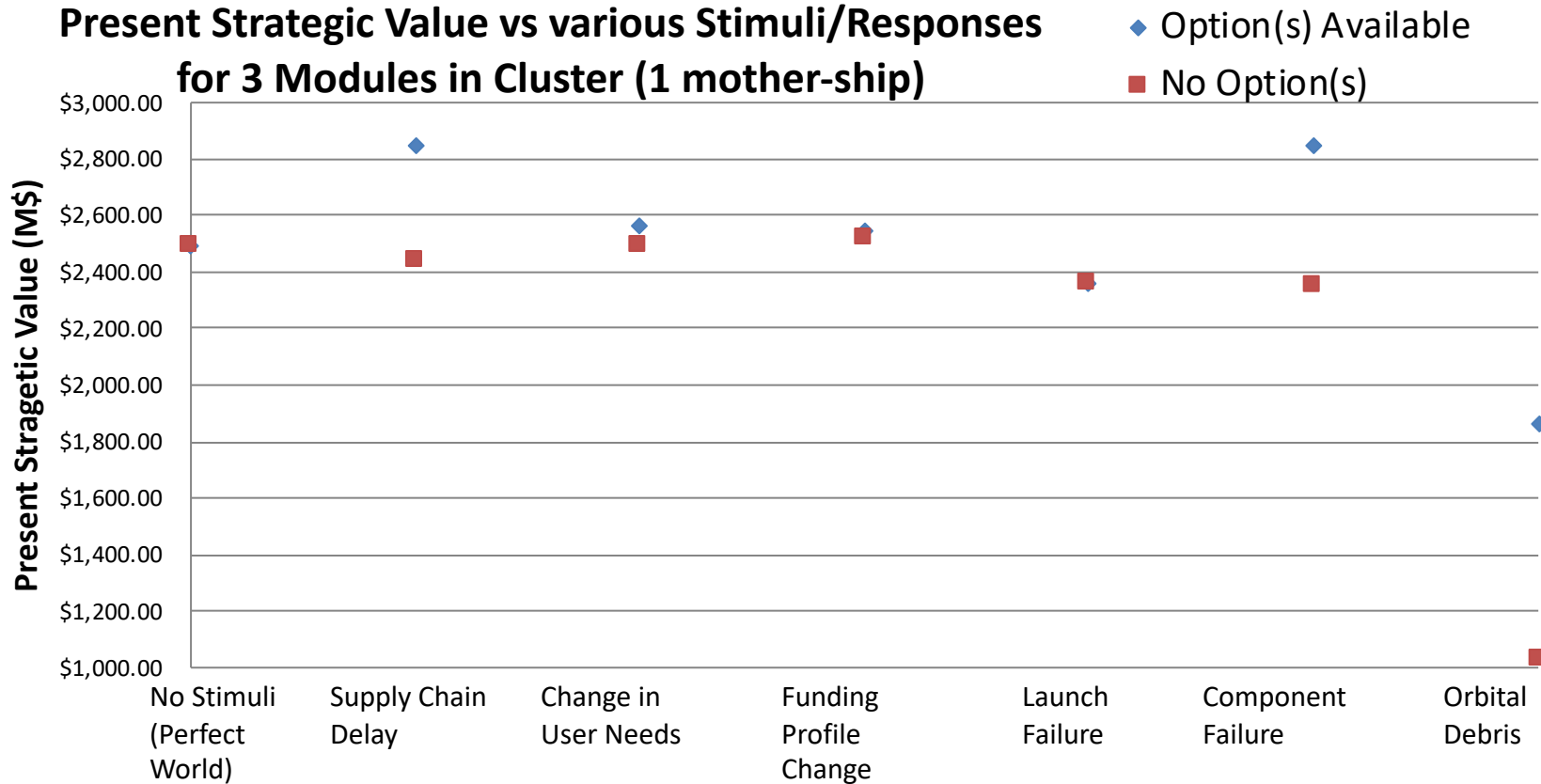


Zooming in to one Tradespace point



Note for this particular (random) case, not all options were worth exercising. For example, cost of replacing a failed component near the end of the 20 year operational time span was not worth the additional data to be obtained.

Zooming in to another Tradespace point



PPS (Stimuli Number)

Note for this particular (random) case, not all options were worth exercising. For example, cost of replacing a failed launch near the end of the 20 year operational time span was not worth the additional data to be obtained.

JPL Mission Statement

- To explore planetary systems -- both our own solar system and others nearby.
- To understand the origins and evolution of the universe and the laws that govern it.
- To search for life beyond Earth.
- To understand our home planet and help protect its environment by making critical measurements.
- To link scientists and the public throughout the solar system by operating the Deep Space Network.
- **To address challenge of national significance by applying unique JPL talent.**
- To support the human expansion into deep space by using JPL robotic capabilities.
- To inspire the next generation of explorers, scientists and engineers.